

**USGS Cooperative Agreement for Geodetic Monitoring Operations  
Final Technical Report May 31, 2020**

Reporting Period: 03/01/2015 through 02/28/2020

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C.A. Start Date & End Date: 03/01/2015 through 02/28/2020

Geodetic Monitoring Project Name:  
**EHP Geodetic Monitoring Operations**

Principal Investigator: Timothy Melbourne  
Email Address: [tim@geology.cwu.edu](mailto:tim@geology.cwu.edu)  
Phone: 509-963-2799

Network contact: Rex Flake  
Email Address: [rex@geology.cwu.edu](mailto:rex@geology.cwu.edu)  
Phone: 509-963-1114

Institution and Address: Geological Sciences  
Central Washington University  
400 E University Way  
Ellensburg, WA 98926-7418

Geodetic Project Web Site: <http://www.panga.cwu.edu>

**Major Goal(s) & Activities of the Geodetic Project:**

PANGA, the CWU Geodesy Lab, currently produces timeseries for over 1,000 GPS/GNSS stations across North America. Of these, 575 stations deemed relevant to Cascadia tectonics are processed within a consistent, Cascadia-stabilized reference frame (see figure 1). In addition to this processing, PANGA maintains a core network of 255 sites across Washington and Oregon states (see figure 2).

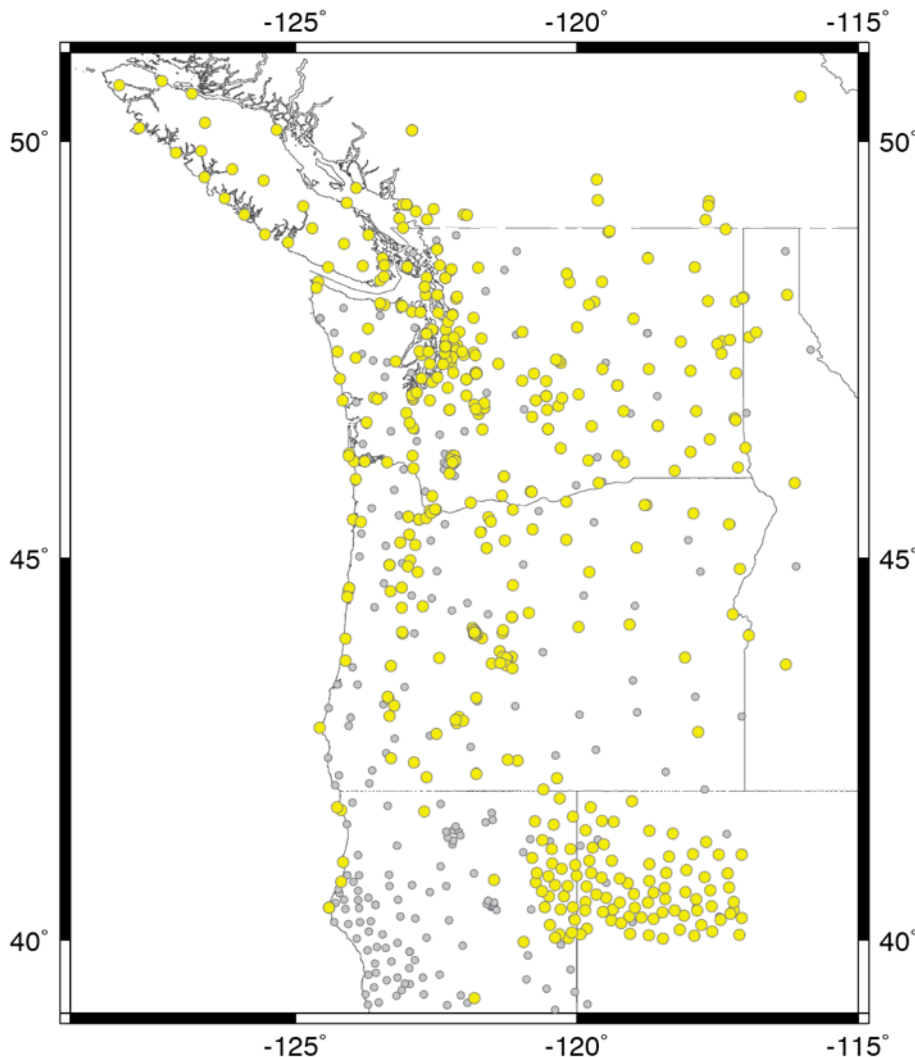


Figure 1: 575 of the sites deemed relevant to Cascadia in the PANGA processing (NOTA in grey, other in yellow).

These activities include daily downloading, public archiving, and processing, with the goal of making the sub-daily and real-time routines used by surveying professionals useful for tectonic monitoring. The resulting station density afforded by the additional sites within the independent PANGA Network considerably improves slip models and identification of the transient slip itself on the deeper Cascadia subduction zone and provides better-resolved surface strain maps. Where NOTA coverage was necessarily bare-bones (for example east of the Cascades) addition of these stations provides tighter bracketing of known seismogenic zones. To refine and streamline the use of GPS/GNSS solutions we have improved and standardized all metadata for GNSS sites analyzed by PANGA, developed a comprehensive software product to analyze real-time GNSS signals, constructed an independent data communications system, and have worked closely with USGS seismologist to collocate strong ground motion instruments with existing coastal PANGA GNSS sites. We have also occupied past campaign benchmarks across the OWL, all while providing necessary maintenance and engaging in close collaboration with our partners to ensure continuous GNSS signals and data quality across Cascadia. We have also implemented the GSAC software to search all our archived data, setup an Ntrip caster to access our real-time data streams and continue to update our metadata for all our independently operated sites.

### Major Objective & Activities for this Reporting Period:

Apart from the timeseries solutions produced by the PANGA geodesy laboratory, the core network of PANGA comprises 255 unique stations apart from NOTA- and USGS/CVO-operated stations extending throughout the Pacific Northwest (see figure 2). During this project our lab has stayed up and running with all data collected and archived with metadata intact. This cooperative agreement supports in part: 1) network maintenance and collaborative expansion, 2) maintenance of a PANGA metadata database, 3) conforming our system to the *Geodetic Network Standards and Procedures*, and 4) daily processing of these stations in addition to over 320 other (NOTA, BARD, etc) Cascadia-relevant GNSS stations within a consistent, Cascadia-optimized reference frame and the public archiving of those products. All of these were achieved.

### Changes to stated goals and activities:

There are no changes to our goals and activities.

### Map of Cascadia Geodetic Stations:

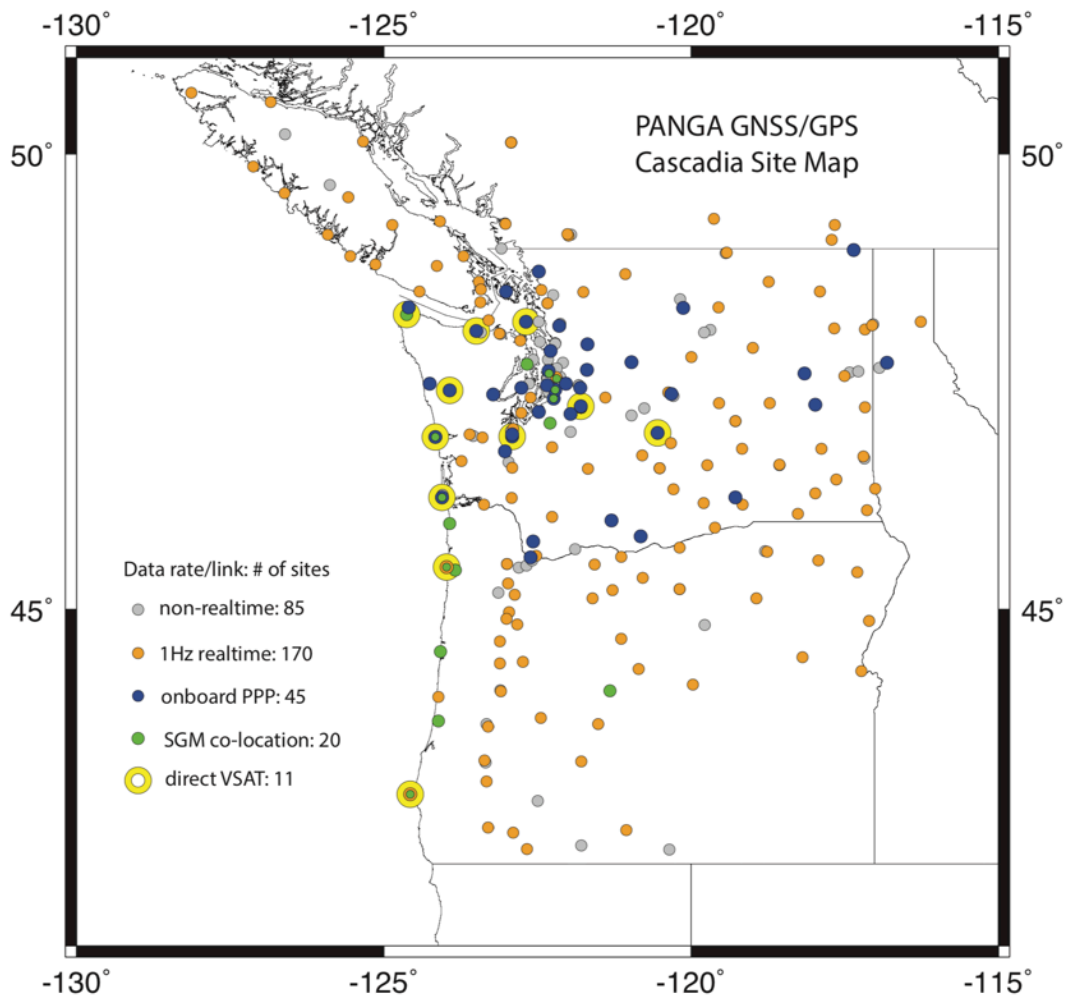


Figure 2: Map of PANGA site locations w/ data sampling rate, onboard precise point positioning, strong ground motion collocation and direct VSAT communications.

### Summary of field visits for this project:

During this cooperative agreement period, we have upgraded many sites to include onboard precise point positioning. This required visiting each site listed and either replacing the existing receiver with a Trimble NetR9 or reconfiguring the physical ports of an existing receiver to accommodate this transition. Sites upgraded include: ARLI, BDRY, BELI, BILS, COUP, CPUD, CSKI, CULM, CUSH, DEEJ, DVPT, ELSR, ENUM, GLWD, GOLY, GRMD, HAHD, KOOT, LINH, LSIG, LWCK, LWST, MKAH, NINT, OCEN, OLAR, OYLR, PDXA, PFLD, PTAA,

QMAR, RICH, SAMM, SKGT, SMAI, SPDA, SPKN, SPRG, SSHO, TACO, TUMW, TWSP, UFDA, VCWA, and WEBG. Additionally, power backups were also installed at these strategic coastal sites: CABL, CHCM, CHZZ, and NEAH. We continue to maintain backup power at: COUP, DEEJ, ELSR, GTPS, HAHD, LFLO, LWCK, OCEN, OLAR, ONAB, PTAA, RDL2, REED, RKD1, SEAS, TILL, XANE and YONC.

Early in year-3 of this project we discovered an issue with the real-time data streams coming from the Topcon Net-G3A's of our network. The timeseries computed with our in-house PPP (Fastlane) software were showing unexplainable intermittent excursions relative to sites with receivers from other manufacturers (e.g., Trimble and Leica). Changing from Topcon's proprietary "GGD Full" streaming protocol to a simple Binex data stream for these real-time feeds solved the problem. This was accomplished remotely for most sites with the exception of: CCPW, KENI, LCRS, OKNG, SEQM, SPKN, and UFDA that required site visits. We continue to replace these aging Topcon Net-G3A's (mostly with NetR9 as mentioned above).

Many cellular carriers have suspended support for 3G modems effective January 1<sup>st</sup> 2019. We have installed new 4G/5G LTE modems at CATH, CHCM, CROK, GHCC, JOBO, MONT, RKD1, SEQM, VCWA, XANE, GTPS, ONAB, RDL2, RSBG, YONC, REED, and at these strong-ground-motion (SGM) co-locate sites: LFLO, P191, P400, P402, P403, P405, P415, P397, P436, P439, P732, RYMD, SEAS, and TILL.

#### **Accomplishments & Changes Implemented in this project:**

All four of the objectives listed above were achieved during this cooperative agreement. We continue to obtain and archive data from new stations in the region as they become available and are currently providing velocity field solutions for around 1,000 GPS/GNSS sites deemed relevant to the western US. To this end, we collaborate with many Washington, Oregon, and California state and county agencies, the Canadian province of British Columbia, and personnel and private network operators to ensure seamless operations and data product services.

PANGA is a Geodetic Seamless Archive Center consistent with other GNSS data repository centers. All data in our archive can be accessed through the GSAC software that was developed by UNAVCO. To streamline the flow of real-time data we continue to run our own Ntrip caster that broadcasts all the Pacific Northwest RTCM 3.0 data streams from all our separate sources. These data can now be accessed with a single login from a single location.

During this project we continued to maintain our publicly available GNSS/GPS sites webpage where each site has separate tabs linking to timeseries, maps, metadata (in tabular and IGS site log form), and data quality plots (see appendix A).

We have constructed several new monuments throughout this project: ROKY, RDTP, CHST, GHCL, JKPR, and BLDG (see figure 3). RDTP on Red Top Mountain to the northwest of our campus in Ellensburg, WA (see figure 4) is interesting for a few reasons. First, it is directly above a recent swarm of seismic activity. Second, it provides much needed constraints for strain calculations across the contracting Kittitas Valley. And lastly, the site doubles as a radio repeater with a clear sky view of peaks along the Cascade crest and CWU.



Figure 3: New PANGA sites CHST, GHCL, ROKY, and JKPR.



Figure 4: New PANGA site RDTP

In the final year of this project we took over responsibility for five NOTA sites that were slated to be decommissioned: BLYN, P064, P442, P444 and SC03. The continuation of time-series from these sites is important as they are among the longest running in the state. The first of these, BLYN, was determined to be useless due to poor data quality. But, after maintaining the site the data improved drastically. Equipment upgrades are still needed as shown by the noise over this past winter (see figure 5). We will continue to operate these five sites and make the data available via our archive.

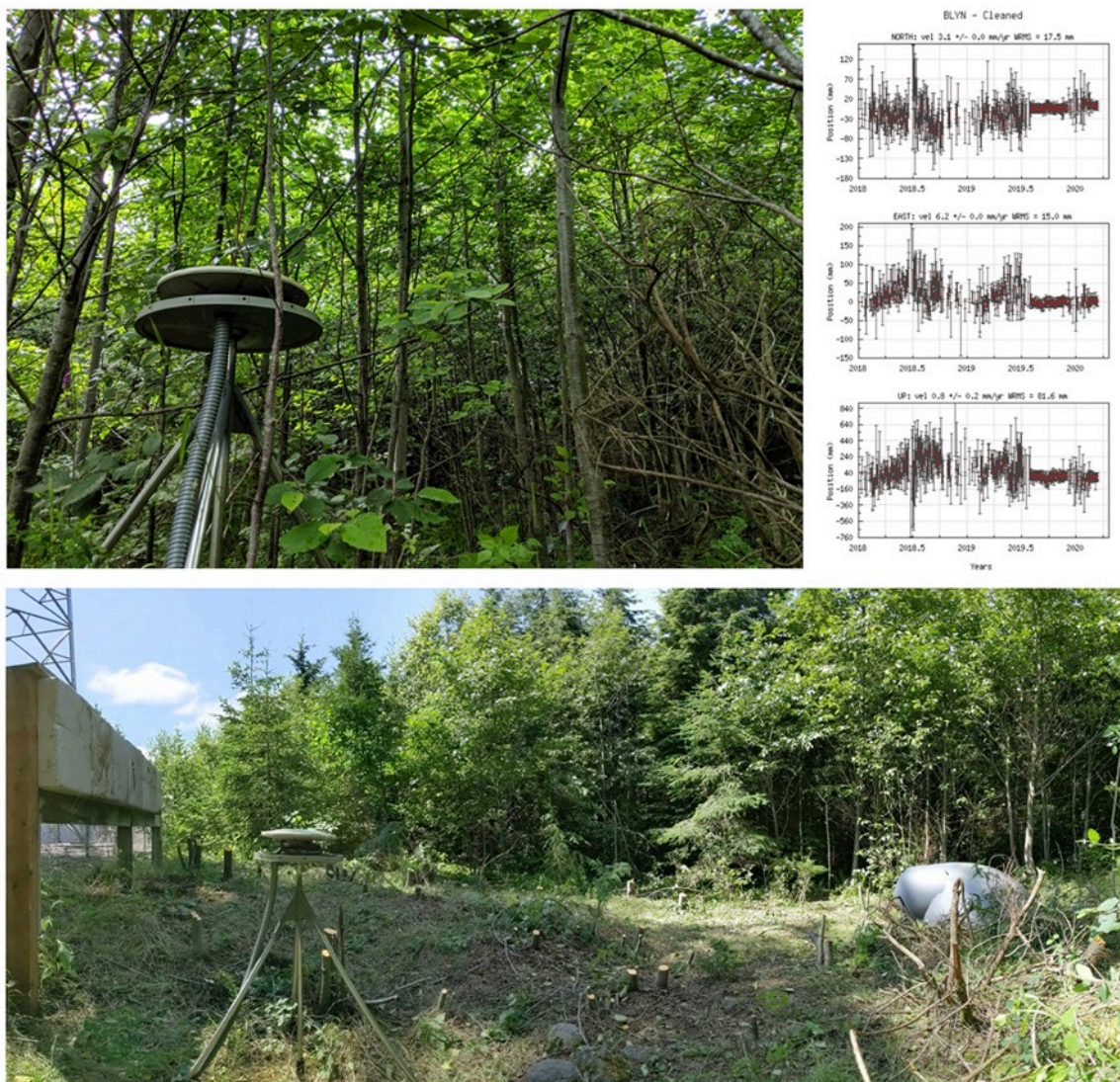


Figure 5: BLYN fix. The timeseries quality recovered to historical values after maintaining the site. However, there was some noise over the past winter. We plan to upgrade the equipment to solve this ongoing issue.

The introduction of a leap second at the end of 2016 caused some issue with the Topcon Net-G3A of our network. Topcon had developed a special firmware package for these units to allow numerical port forwarding but this version was not programmed for the leap second and support for these units has been discontinued. We negotiated for a fix and all 60 plus of these have now been updated. Many updates could not be accomplished remotely and therefore required site visits. We have now replaced most all these aging Topcon Net-G3A's with Trimble NetR9's that have full GNSS and onboard precise point positioning (PPP).

PANGA is comprised of a consortium of separate managing subnet entities, and as such, there are varying levels of attention to the quality of metadata reported by our partners. During this project, we continued to verify documented metadata for all the sites we process and archive. Many of these required site visits, phone calls to managing entities, and close inspection of data inconsistencies. Routine maintenance is imperative and we have replaced aging batteries at many sites such as ELSR and PFLD (see figure 6) among many others.



Figure 6. Routine battery replacements are required at many sites such as ELSR (left) and PFLD (right).

### Major Goal(s) & Activities Moving Forward

We will continue to archive RINEX files and provide daily solutions for 255 GPS/GNSS distinct stations across the Pacific Northwest (in addition to those operated by NOTA). In real-time these comprise the Washington State Reference Network (WSRN; 105 stations), Oregon Real-time GPS Network (ORGN; 45 stations), various privately run real-time GNSS networks (RGPS; 56 stations), and Western Canada Deformation Array (GSC-NRCan; 27 stations). We process static data from most of these stations, along with 380 select sites from NOTA and the Cascades Volcano Observatory (CVO; 22 stations) in global and North American reference frames using the Jet Propulsion Laboratory's GIPSY-OASIS software package. The list of current real-time data streams we process is provided below. We will continue to upgrade stations, replace power backup systems, and improve data communications.

### Spending and Drawdown Status:

All funds will be expended as of 02/29/19.

### Problems encountered and useful lessons:

In 2017 we discovered an issue with the real-time data streams coming from the Topcon Net-G3A's of our network. The time series computed with our in-house PPP (Fastlane) software were showing unexplainable intermittent excursions relative to sites with receivers from other manufacturers (e.g., Trimble and Leica). We continue to replace these aging Topcon Net-G3A's (mostly with NetR9 as discussed in "Field Visits" section).

We continue to encounter problems with many of the Rinex headers in our archived data. The site logs provide the most accurate metadata for each station but the raw data stream headers captured to create daily files don't always reflect the changes recorded in the IGS site logs. We continue to improve these data headers and provide a disclaimer on our download sites instructing end users to utilize the IGS site logs for the necessary processing parameters. As discussed above, we solved the Topcon data streams by switching to Binex.

### 1Hz Real-time Stations w/ Onboard Precise Point Positioning

Site	Lat	Lon	City	St.	Receiver	Antenna	Comms	Latency (s)	SGM (m)
ARLI	48.17	-122.14	Arlington	WA	TRIMBLE NETR3	TRM55971.00 SCIT	CDMA	0.607	
BDRY	48.99	-117.35	Boundary Lake	WA	TRIMBLE NETR9	TRM115000.00 SCIT	CDMA	0.512	
BELI	48.76	-122.48	Bellingham	WA	TRIMBLE NETR9	TRM55971.00 NONE	ETHR	0.309	
BILS	47.54	-124.25	Queets	WA	TRIMBLE NETR9	TRM57971.00 SCIT	ETHR	0.237	94
CHCM	48.01	-122.78	Chimacum	WA	TRIMBLE NETR9	TRM57971.00 SCIT	CDMA	0.322	
COUP	48.22	-122.69	Coupeville	WA	TRIMBLE NETR9	TRM57971.00 SCIT	VSAT	0.772	

CPUD	47.43	-120.31	Wenatchee	WA	TRIMBLE NETR9	TRM57971.00 TZGD	ETHR	0.425	
CSKI	47.38	-122.24	Kent	WA	TRIMBLE NETR9	TRM57971.00	CDMA	0.643	1223
CULM	47.98	-121.69	Spada Lake	WA	TRIMBLE NETR9	TRM57971.00	CDMA	nan	
CUSH	47.42	-123.22	Lake Cushman	WA	TRIMBLE NETR9	TRM55971.00 NONE	ETHR	0.467	
DEEJ	47.47	-123.93	Amanda Park	WA	TRIMBLE NETR9	TRM57971.00	VSAT	0.615	
DVPT	47.66	-118.15	Davenport	WA	TRIMBLE NETR9	TRM115000.00 NONE	CDMA	0.365	
ELSR	47.5	-122.76	Bremerton	WA	TRIMBLE NETR9	TRM57971.00 SCIT	CDMA	0.664	793
ENUM	47.21	-121.96	Enumclaw	WA	TRIMBLE NETR9	TRM57971.00 SCIT	ETHR	nan	
GLWD	46.02	-121.29	Glenwood	WA	TRIMBLE NETR9	TRM55971.00 SCIT	CDMA	0.471	
GOLY	45.84	-120.81	Goldendale	WA	TRIMBLE NETR9	TRM115000.00	CDMA	0.639	
GRMD	46.8	-123.02	Grand Mound	WA	TRIMBLE NETR9	TRM57971.00 SCIT	CDMA	0.747	1532
HAHD	47.29	-121.79	Palmer	WA	TRIMBLE NETR9	TRM57971.00 SCIT	VSAT	0.771	
KOOT	47.77	-116.81	Couer D'Alene	ID	TRIMBLE NETR9	TRM57971.00 SCIT	CDMA	0.758	
LINH	47	-120.54	Ellensburg	WA	TRIMBLE NETR9	TPSCR.G3 NONE	CDMA	0.764	
LSIG	47.7	-121.69	Tolt	WA	TRIMBLE NETR9	TRM57971.00 SCIT	ETHR	0.25	44
LWCK	46.28	-124.05	Ilwaco	WA	TRIMBLE NETR9	TPSCR.G3 SCIT	CDMA	0.601	37
LWST	46.37	-117	Lewiston	ID	TRIMBLE NETR9	TRM115000.00 NONE	ETHR	0.319	
MKAH	48.37	-124.59	Makah	WA	TRIMBLE NETR9	TRM115000.00 NONE	CDMA	0.629	13
NINT	47.5	-121.8	North Bend	WA	TRIMBLE NETR9	TRM115000.00 NONE	CDMA	0.38	1164
OCEN	46.95	-124.16	Ocean Shores	WA	TRIMBLE NETR9	TRM57971.00 SCIT	VSAT	0.369	24
OLAR	46.96	-122.91	Olympia	WA	TRIMBLE NETR9	TRM57971.00 SCIT	VSAT	1.1	
OYLR	47.47	-122.2	Renton	WA	TRIMBLE NETR9	TRM57971.00 TZGD	CDMA	0.765	1583
PDXA	45.6	-122.61	Portland	OR	TRIMBLE NETR9	TRM55971.00 TZGD	ETHR	0.756	
PFLD	47.9	-122.28	Everett	WA	TRIMBLE NETR9	TRM55971.00 SCIT	CDMA	0.632	
PTAA	48.12	-123.49	Port Angeles	WA	TRIMBLE NETR9	TPSCR.G3 SCIT	VSAT	0.92	
QMAR	47.78	-120.97	Stevens Pass	WA	TRIMBLE NETR9	TRM55971.00 TZGD	ETHR	0.399	
RICH	46.28	-119.28	Richland	WA	TRIMBLE NETR9	TRM115000.00 NONE	ETHR	0.461	
SAMM	47.54	-122.03	Issaquah	WA	TRIMBLE NETR9	TRM57971.00 NONE	CDMA	0.4	
SKGT	48.43	-122.34	Mount Vernon	WA	TRIMBLE NETR9	TRM115000.00 NONE	CDMA		
SMAI	47.52	-122.35	Seattle	WA	TRIMBLE NETR9	TRM57971.00 NONE	ETHR	0.248	
SPDA	47.94	-121.68	Spada Lake	WA	TRIMBLE NETR9	TRM57971.00 NONE	CDMA		
SPKN	47.63	-117.5	Spokane	WA	TRIMBLE NETR9	TRM57971.00 SCIT	ETHR	0.46	
SPRG	47.31	-117.98	Sprague	WA	TRIMBLE NETR9	TRM55971.00 SCIT	ETHR	0.329	
SSHO	47.68	-122.32	Seattle	WA	TRIMBLE NETR9	TRM115000.00 NONE	ETHR	0.836	
TACO	47.23	-122.47	Tacoma	WA	TRIMBLE NETR9	TRM57971.00 NONE	CDMA	0.747	
TUMW	46.98	-122.91	Tumwater	WA	TRIMBLE NETR9	TRM57971.00 NONE	ETHR	0.533	
TWSP	48.37	-120.12	Twisp	WA	TRIMBLE NETR9	TRM115000.00 NONE	CDMA	0.698	
UFDA	47.76	-122.67	Poulsbo	WA	TRIMBLE NETR9	TRM115000.00 NONE	ETHR	0.371	1837
WEBG	45.78	-122.56	Battleground	WA	TRIMBLE NETR9	TRM55971.00 NONE	CDMA	0.74	
VCWA	45.62	-122.52	Vancouver	WA	TRIMBLE NETR9	TRM115000.00 NONE	CDMA	0.362	

### Real-time Stations

Site	Lat	Lon	City	St.	Receiver	Antenna	Comms	Latency (s)	SGM (m)
AL2H	48.23	-123.29	Victoria	BC	SEPT POLARX5	AOAD/M_T SCIS	ETHR	0.505	
ANAT	46.13	-117.13	Anatone	WA	LEICA GRX1200+GNSS	LEIAT504GG LEIS	ETHR	0.331	

ARLN	45.71	-120.18	Arlington	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.279	
ASHL	42.18	-122.67	Ashland	OR	LEICA GRX1200+GNSS	LEIAR25.R4 LEIT	ETHR	0.262	
ATLI	59.59	-133.71	Atlin	BC	TRIMBLE NETR8	TRM59800.00	ETHR	0.482	
BAMF	48.84	-125.14	Bamfield	BC	SEPT POLARX5	SEPCHOKE_B3E6 SPKE	ETHR	0.567	
BCES	48.43	-123.43	Victoria	BC	TRIMBLE NETR9	TRM59800.00 SCIS	ETHR	0.646	
BCOV	50.54	-126.84	Beaver Cove	BC	SEPT POLARX5	LEIAT504 SCIS	ETHR	0.556	
BCRK	62.41	-140.86	Beaver Creek	YK	TRIMBLE NETR8	TRM59800.00	ETHR	nan	
BEND	44.06	-121.32	Bend	OR	LEICA GRX1200PRO	LEIAT504 LEIS	ETHR	0.262	1474
BIGD	47.93	-118.99	Grand Coulee	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.365	
BLY1	42.41	-121.05	Bly	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.304	
BPKT	46.88	-120.33	Kittitas	WA	TPS NET-G3A	TPSCR.G3 SCIT	CDMA	0.352	
BRN3	49.27	-123.02	Burnaby	BC	TRIMBLE NETR5	TRM55971.00 NONE	ETHR	0.278	
CATH	46.2	-123.37	Cathlamet	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.376	
CBLV	47.61	-122.19	Bellevue	WA	TRIMBLE NETR9	TRM59800.00 SCIS	ETHR	0.43	
CCPW	46.32	-117.98	Dayton	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	0.469	
CHEL	47.83	-119.99	Chelan	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.363	
CHEM	43.22	-121.79	Chemalt	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.28	
CHLW	49.14	-122	Chilliwack	BC	TRIMBLE NETR9	TRM57971.00 NONE	ETHR	0.386	
CHST	46.61	-122.91	Chehalis	WA	TPS NET-G3A	TPSCR.3G NONE	CDMA	0.32	
CHWK	49.16	-122.01	Chilliwack	BC	TRIMBLE NETR5	TRM29659.00 SCIS	CDMA	0.613	
CLRS	48.82	-124.13	Mesachie Lake	BC	SEPT POLARX5	TRM29659.00 SCIS	ETHR	0.609	
CNCR	48.54	-121.75	Concrete	WA	LEICA GRX1200GGPRO	LEIAX1202 NONE	ETHR	0.296	
COBO	45.24	-120.18	Cobocon	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	nan	
COLV	48.54	-117.9	Colville	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	0.24	
COND	45.24	-120.18	Condon	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.29	
COUG	46.06	-122.26	Cougar	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	nan	
CPXF	46.84	-122.26	Lagrande,WA	WA	LEICA RS500	LEIAT504GG LEIS	ETHR	0.343	
CROK	46.27	-122.91	Castle Rock	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.333	
CSTL	49.26	-117.66	Castlegar	OR	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	nan	
CTPT	42.38	-122.89	Central Point	OR	LEICA GRX1200+GNSS	LEIAR25.R4 LEIT	ETHR	0.267	
DMND	48.14	-117.16	Diamond Lake	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.368	
DR2O	49.32	-119.63	Penticton	BC	TRIMBLE NETR9	AOAD/M_T NONE	ETHR	0.481	
ELG2	45.56	-117.93	Elgin	OR	Leica GRX1200GGPRO	LEIAR20 LEIM	ETHR	0.275	
ELIZ	49.87	-127.12	Eliza Dome	BC	SEPT POLARX5	LEIAT504 SCIS	ETHR	0.57	
ENTR	45.43	-117.29	Enterprise	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.236	
EPHR	47.33	-119.54	Ephrata	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.41	
FWBD	44.29	-117.22	Farewell Bend	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.294	
GHCL	46.95	-123.8	Grays Harbor	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	nan	
GRAS	45.36	-120.79	Grass Valley	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	1.445	
GRCK	48.14	-117.66	Grouse Creek	WA	TPS NET-G3A	TPSCR.G3	CDMA	0.543	
GTPS	42.43	-123.3	Grants Pass	OR	LEICA GRX1200+GNSS	LEIAR25.R4 LEIT	ETHR	0.259	
HALF	44.87	-117.1	Halfway	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.558	
HOLB	50.64	-128.14	Holberg	BC	SEPT POLARX5	SEPCHOKE_B3E6 SPKE	ETHR	0.837	
JIME	45.52	-122.99	Hillsboro	OR	LEICA GR10	LEIAS10 NONE	ETHR	0.34	
JOBO	48.56	-122.44	Edison	WA	TRIMBLE NETR5	TPSCR.G3 TPSH	CDMA	0.329	

KENI	46.2	-119.16	Kenniwick	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	0.287	
KLTS	46.64	-118.56	Kahlotus	WA	TRIMBLE NETR5	TRM55971.00 SCIT	ETHR	0.313	
LAPN	43.66	-121.51	LaPine	OR	LEICA GRX1200PRO	LEIAT504 LEIS	ETHR	0.273	
LCRS	46.82	-117.88	Lacrose	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	2.911	
LCS1	44.63	-123.11	Albany	OR	TRIMBLE NETR9	TRM57971.00	ETHR	0.232	
LCS2	44.4	-122.73	Sweet Home	OR	TRIMBLE NETR9	TRM57971.00	ETHR	0.247	
LCS3	44.38	-123.11	Halsey	OR	TRIMBLE NETR9	TRM57971.00	ETHR	0.253	
LFLO	43.98	-124.11	Florence	OR	LEICA GRX1200PRO	LEIAT504 LEIS	ETHR	0.466	
LMID	46.37	-120.28	Toppenish	WA	TPS NETG3	TPSCR.G3 TPSH	CDMA	0.432	
LNGB	47.22	-122.76	Longbeach	WA	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.364	
LPSB	44.05	-123.09	Eugene	OR	LEICA GRX1200	LEIAT504 LEIS	ETHR	0.254	
LTAH	47.28	-117.16	Latah	WA	TPS NET-G3A	TPSCR.G3 SCIT	CDMA	0.378	
MCSO	44.97	-122.96	Salem	OR	LEICA GRX1200PRO	LEIAT504 LEIS	ETHR	nan	
MDRS	44.66	-121.13	Madras	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.279	
MLKE	47.13	-119.27	Moses Lake	WA	TPS NET-G3A	TPSPG_A1+GP	ETHR	0.257	
MONT	46.98	-123.6	Montesano	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	0.666	
MYRA	49.55	-125.57	Vancouver Is.	BC	SEPT POLARX5	SEPCHOKE_B3E6 SPKE	ETHR	0.716	
NANO	49.29	-124.09	NanOOSE Bay	BC	SEPT POLARX5	SEPCHOKE_B3E6 SPKE	RTHR	0.512	
NTKA	49.59	-126.62	Nootka Island	BC	LEICA GRX1200PRO	LEIAT504 SCIS	ETHR		
NWBG	45.3	-122.98	Newberg	OR	TRIMBLE NETRS	TRM41249.00 TZGD	ETHR	0.368	
NWPT	48.18	-117.05	New Port	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	nan	
OAKR	43.74	-122.44	Oakridge	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.308	
ODOT	44.9	-123	Salem	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.274	
ODSA	47.33	-118.71	Odessa	WA	TRIMBLE NETR8	TRM57971.00 NONE	CDMA	0.397	
OKNG	48.37	-119.55	Okanagon	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	0.474	
OLMP	47.04	-122.9	Olympia	WA	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	0.613	
ONAB	44.51	-124.07	Ona Beach	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	nan	46
OTHL	46.82	-119.17	Othello	WA	TRIMBLE NETR5	TRM57971.00 NONE	CDMA	0.316	
PDTN	45.67	-118.76	Pendleton	OR	TPS NET-G3A	TPSCR.G3	ETHR	0.232	
PGC5	48.65	-123.45	North Saanich	BC	SEPT POLARX5	TRM29659.00 SCIS	ETHR	0.45	
PKDL	45.52	-121.56	Parkdale	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	nan	
PKWD	46.6	-121.68	Packwood	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.441	
PLMN	46.73	-117.19	Pullman	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.347	
PLNA	44.13	-119.97	Paulina	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.297	
PNVL	44.31	-120.85	Prineville	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.281	
POME	46.48	-117.63	Pomeroy	WA	LEICA GRX1200+GNSS	LEIAT504GG LEIS	ETHR	nan	
PRDY	47.39	-122.61	Purdy	WA	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	nan	
PRSR	46.22	-119.79	Prosser	WA	TPS NET-G3A	TPSCR.G3 NONE	CDMA	0.434	
PTAL	49.26	-124.86	Port Alberni	BC	SEPT POLARX5	TRM29659.00 SCIS	ETHR	0.642	
PTRF	48.54	-124.41	Port Renfrew	BC	SEPT POLARX5	TRM29659.00 SCIS	ETHR	0.603	
PTSN	45.94	-119.61	Patterson	WA	LEICA GRX1200+GNSS	LEIAT504GG LEIS	CDMA	0.547	
QUAD	50.13	-125.33	Quadra Island	BC	TRIMBLE NETRS	SEPCHOKE_B3E6 SPKE	ETHR	0.483	
REED	43.7	-124.11	Reedsport	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.284	37
RKD1	48.96	-119.41	Oroville	WA	TPS NET-G3A	TPSCR.G3 SCIT	CDMA	0.36	
RMRK	46.75	-120.79	Naches	WA	LEICA GRX1200+GNSS	LEIAT504GG LEIS	ETHR	nan	

ROSS	48.73	-121.07	Concrete	WA	TRIMBLE NETRS	TRM29659.00 SCIT	CDMA	nan	
RPUB	48.65	-118.73	Republic	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.361	
RSBG	43.24	-123.36	Roseburg	OR	LEICA GRX1200+GNSS	LEIAT504GG LEIS	ETHR	0.264	
RYA1	48.22	-116.26	Sandpoint	ID	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.351	
RYMD	46.68	-123.73	Raymond	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.36	
SACH	48.57	-123.42	Saanichton	BC	TPS NET-G3A	TPSCR.G3 TPSH	ETHR	nan	
SC04	48.92	-123.7	Chemainus	BC	SEPT POLARX5	TRM29659.00 SCIS	ETHR	0.614	
SEAS	45.98	-123.92	Seaside	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.262	1491
SEQM	48.09	-123.11	Sequim	WA	TPS NET-G3A	TPSCR.G3 TPSH	CDMA	0.366	
SNOQ	47.39	-121.39	Snoqualmie	WA	LEICA GRX1200+GNSS	LEIAR10	ETHR	0.276	
STAY	44.83	-122.82	Stayton	OR	LEICA GRX1200PRO	LEIAT504 LEIS	ETHR	0.267	
SUHS	42.99	-123.33	Myrtle Creek	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	nan	
TDLS	45.61	-121.13	The Dalles	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.282	
TFNO	49.15	-125.91	Tofino	BC	SEPT POLARX5	SEPCHOKE_B3E6 SPKE	ETHR	0.514	
THUN	47.11	-122.29	Puyallup	WA	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.304	643
TILL	45.46	-123.83	Tillamook	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.857	11
TRAI	49.1	-117.71	Trail	BC	TRIMBLE NETR9	TRM55971.00 NONE	ETHR	0.284	
UCLU	48.93	-125.54	Ucluelet	BC	SEPT POLARX5	SEPCHOKE_B3E6 SPKE	ETHR	0.613	
UKIA	45.13	-118.94	Ukiah	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	ETHR	0.292	
VRNT	46.64	-119.73	Vernita	WA	LEICA GRX1200+GNSS	LEIAT504GG LEIS	ETHR	0.275	
WALA	46.09	-118.26	Walla Walla	WA	LEICA GRX1200+GNSS	LEIAT504GG LEIS	CDMA	0.427	
WAMC	45.22	-121.27	Wamic	OR	LEICA GRX1200GGPRO	LEIAR25.R4 LEIT	ETHR	nan	
WDBN	45.17	-122.87	Woodburn	OR	LEICA GRX1200PRO	LEIAT504 LEIS	ETHR	0.298	
WILL	52.24	-122.17	Williams Lake	BC	TRIMBLE NETR9	TRM59800.00 SCIS	ETHR	0.636	
WMSG	45.13	-121.6	Gov. Camp	OR	Leica GRX1200GG Pro	LEIAT504GG LEIS	ETHR	0.282	
WOSB	50.13	-122.92	Whistler	BC	SEPT POLARX5	AOAD/M_T SCIS	ETHR	0.688	
WSLB	50.13	-122.92	Whistler	BC	SEPT POLARX5	AOAD/M_T SCIS	ETHR	0.687	
XANE	47.44	-120.37	Wenatchee	WA	TPS NET-G3A	TPSCR.G3 SCIT	CDMA	0.366	
YAKI	46.6	-120.51	Yakima	WA	TRIMBLE NETR5	TRM55971.00 NONE	ETHR	0.279	
YELM	46.95	-123.39	Yelm	WA	LEICA GRX1200GGPRO	LEIAT504GG LEIS	CDMA	nan	
YONC	43.63	-123.3	Drain	OR	Leica GRX1200GG Pro	LEIAT504GG LEIS	ETHR	0.274	

### Daily Downloads and Historical Sites

Site	Lat	Lon	City	St.	Receiver	Antenna	Comms*	Data Status
AXIS	47.40	-120.28	Wenatchee	WA	LEICA GRX1200GGPRO	LEIAX1202GG	NA	20161111
BAYV	48.00	-122.46	Bayview	WA	TRIMBLE 5700	TRM41249.00	DC	20050402
BCIT	47.61	-122.19	Bellevue	WA	TRIMBLE NETR9	TRM59800.00 SCIS	DD	current
BDRD	47.28	-121.79	Palmer	WA	TRIMBLE NETRS	TRM41249.00 NONE	DC	none
BDRH	47.28	-121.79	Palmer	WA	TRIMBLE NETR5	TRM55971.00	DC	none
BELV	47.60	-122.18	Bellevue	WA	TRIMBLE 4700	TRM22020.00+GP	DC	20071228
BFIR	47.62	-122.13	Bellevue	WA	TRIMBLE NETR9	TRM59800.00 SCIS	NA	20170123
BLVU	47.60	-122.18	Bellevue	WA	TRIMBLE 4700	TRM33429.00+GP	DC	20090504
BRDG	47.28	-121.79	Palmer	WA	TRIMBLE 5700	TRM41249.00 NONE	DC	none
BREW	48.13	-119.68	Brewster	WA	ASHTech UZ-12	ASH701945C_M SCIT	DC	20150726

BRNB	49.28	-123.02	Burnaby	BC	TRIMBLE NETR5	TRM55971.00 TZGD	DC	20130616
BSUM	47.55	-122.13	Newcastle	WA	TRIMBLE NETR9	TRM59800.00 SCIS	DD	current
BTON	45.49	-122.80	Beaverton	OR	ASHTech Z-XII3	ASH700718B	DC	20090611
CAMI	48.22	-122.48	Camano Island	WA	TRIMBLE 5700	TRM41249.00	DC	20041216
CH2M	47.53	-121.83	Snoqualmie	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20100402
CWAK	49.15	-121.95	Chilliwak	BC	TRIMBLE NETR5	TRM55971.00 NONE	NA	20170622
DCSO	43.21	-123.34	Roseburg	OR	TRIMBLE NETRS	TRM41249.00 TZGD	DC	20140507
DEA1	47.67	-117.42	Spokane	WA	LEICA GRX1200PRO	LEIAX1202	NA	20160302
DEA2	48.75	-122.48	Bellingham	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20100408
DEA3	45.51	-122.67	Portland	OR	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20140923
DWH1	47.77	-122.08	Woodinville	WA	JPS LEGACY	JPSREGANT_DD_E	DC	20070719
EMBC	47.28	-121.79	Palmer	WA	TRIMBLE NETR5	TRM55971.00	DC	none
EMBL	47.28	-121.79	Palmer	WA	TRIMBLE 5700	TRM41249.00 NONE	DC	none
EMBR	47.28	-121.79	Palmer	WA	TRIMBLE NETR8	TRM55971.00 NONE	DC	none
ENM1	47.21	-121.96	Enumclaw	WA	TRIMBLE NETR5	TRM55971.00 SCIT	DC	20130128
ESM1	47.80	-122.57	Kingston	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20120722
FND1	47.28	-121.79	Palmer	WA	TRIMBLE NETR5	TRM55971.00	DC	none
FND2	47.28	-121.80	Palmer	WA	TRIMBLE NETR5	TRM55971.00	DC	none
FRFX	47.01	-121.96	Fairfax Forest	WA	LEICA GRX1200GGPRO	LEIAT504GG	DC	20161122
FRID	48.54	-123.02	Friday Harbor	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20160226
GLDR	49.68	-125.87	Gold River	BC	LEICA GRX1200PRO	LEIAT504	DD	current
GLNW	46.02	-121.29	Glenwood	WA	TRIMBLE 5700	TRM41249.00	DC	20111005
GRP4	48.19	-122.13	Arlington	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20120723
HGP1	47.02	-122.92	Tumwater	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20120723
HTCH	47.19	-120.97	Cle Elum	WA	TRIMBLE NETRS	TRM41249.00	DC	20130731
INW1	47.71	-116.93	Post Falls	ID	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20120622
INW2	48.19	-117.03	Newport	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20090223
IWAC	46.31	-124.04	Ilwaco	WA	JPS ODYSSEY	TPSCR.G3 TPSH	DC	20111130
KAHL	46.64	-118.56	Kahlotus	WA	TRIMBLE NETR5	TRM55971.00	DC	20111011
KANA	48.96	-119.44	Oroville	WA	TPS NET-G3A	TPSPG_A1 NONE	DC	20111027
KFRC	42.22	-121.78	Klamath Falls	OR	TRIMBLE NETRS	TRM41249.00 TZGD	DD	current
KNTP	47.43	-122.26	Kent	WA	JPS ODYSSEY	TPSPG_A1+GP	DC	20080924
KRMT	47.80	-122.32	Lynwood	WA	LEICA GRX1200PRO	LEIAX1202 NONE	DC	20131012
LKVW	42.17	-120.35	Lakeview	OR	LEICA GRX1200GGPRO	LEIAT504GG LEIS	DD	current
MCMV	45.20	-123.13	McMinnville	OR	ASHTech UZ-12	ASH700228A	DC	20050824
MSLK	47.13	-119.27	Moses Lake	WA	TPS NET-G3A	TPSPG_A1+GP	DC	20140814
OBEC	44.07	-123.10	Eugene	OR	TRIMBLE NETRS	TRM41249.00 NONE	DD	current
OTIS	48.42	-122.34	Mt Vernon	WA	TRIMBLE 4700	TRM22020.00+GP	DC	20080109
PCSO	43.66	-123.33	Dallas	OR	TRIMBLE NETR5	LEIAT504 LEIS	NA	20150420
PDXB	45.57	-122.58	Portland	OR	JPS ODYSSEY	TPSCR3_GGD CONE	DC	20081103
PER1	47.98	-122.21	Everett	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20111229
PNCL	48.10	-123.42	Port Angeles	WA	TPS NET-G3A	TPSCR.G3 TPSH	DC	20120124
PNDL	45.67	-118.79	Pendleton	OR	TPS NET-G3A	TPSCR.G3 TPSH	DC	20110301
POUL	47.75	-122.67	Poulsbo	WA	SPP GEOTRACER100	TRM33429.00+GP	DC	20071019
PSEA	47.45	-122.32	Seattle	WA	LEICA GRX1200PRO	LEIAX1202	NA	20140923

PSPT	42.75	-122.49	Prospect	OR	LEICA GRX1200+GNSS	LEIAR25.R4 LEIT	DD	current
PTWA	49.01	-123.08	Tsawassen	WA	LEICA GRX1200GGPRO	GPPNULLANTENNA	NA	20160920
RDTP	47.27	-120.76	Liberty	WA	TRIMBLE NETRS	TRM41249.00 NONE	MD	20161025
SATS	46.97	-123.54	Montesano	WA	TRIMBLE 4000SSI	TRM29659.00	DC	19981231
SEDK	48.50	-122.24	Sedro-Woolley	WA	LEICA GRX1200PRO	LEIAX1202	NA	20120723
SKMA	45.69	-121.88	Stevenson	WA	TPS NET-G3A	TPSCR.G3 TPSH	DC	20140717
SPKV	47.68	-117.27	Spokane	WA	LEICA GRX1200GGPRO	LEIAT504 LEIS	DC	20101215
SPRA	44.83	-119.78	Spray	OR	LEICA GRX1200+GNSS	LEIAT504GG LEIS	DD	current
SPWY	47.28	-121.79	Palmer	WA	TRIMBLE NETRS	TRM55971.00	DC	none
SQIM	48.08	-123.10	Sequim	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20140922
TAY1	46.71	-117.18	Pullman	WA	LEICA GRX1200PRO	LEIAX1202 NONE	NA	20110809
TC__	47.69	-121.69	Tolt Reservoir	WA	TRIMBLE NETRS	TRM41249.00 NONE	DC	none
TN__	47.69	-121.69	Tolt Reservoir	WA	TRIMBLE NETRS	TRM41249.00 NONE	DC	none
TRI1	47.71	-122.19	Kirkland	WA	LEICA GRX1200PRO	LEIAX1202	NA	20110320
TS__	47.69	-121.69	Tolt Reservoir	WA	TRIMBLE NETRS	TRM41249.00	DC	none
TWR1	47.28	-121.79	Palmer	WA	TRIMBLE NETRS	TRM55971.00	DC	none
WABR	48.10	-119.78	Brewster	WA	LEICA GRX1200PRO	LEIAT502 NONE	NA	20171129
WACO	45.52	-122.99	Hillsboro	OR	LEICA RS500	LEIAT503 LEIC	DC	20110706
WACS	46.68	-122.97	Chehalis	WA	LEICA GR10	LEIAR10 NONE	NA	20171223
WAEV	47.98	-122.21	Everett	WA	LEICA GR10	LEIAR10 NONE	DD	current
WAPS	47.45	-122.32	SeaTac	WA	LEICA GR10	LEIAR10 NONE	DD	current
WASQ	47.53	-121.83	Snoqualmie	WA	LEICA GR10	LEIAR10 NONE	DD	current
WCM1	47.54	-122.64	Port Orchard	WA	ASHTech Z-XII3	ASH700718B	DC	20050403
WEEZ	47.98	-122.20	Everett	WA	TRIMBLE NETR3	TRM55971.00	DC	20100805
WNTH	48.46	-120.17	Winthrop	WA	TPS NET-G3A	TPSCR.G3 TPSH	DC	20141017
WSLR	50.13	-122.92	Whistler	BC	TRIMBLE NETRS	AOAD/M_T SCIS	DC	20161115
WOST	50.21	-126.61	Woss	BC	LEICA GRX1200PRO	LEIAT504	NA	20170214
YAWA	46.60	-120.51	Yakima	WA	TRIMBLE 4000SSI	TRM22020.00+GP	DC	20080819
VERN	48.42	-122.34	Mt. Vernon	WA	LEICA GRX1200GGPRO	LEIAX1202 NONE	DD	current
V081	47.60	-122.34	Seattle	WA	TRIMBLE NETRS	TRM41249.00	DC	20171201
V096	47.60	-122.34	Seattle	WA	TRIMBLE NETRS	TRM41249.00	DC	20171201
V102	47.60	-122.34	Seattle	WA	TRIMBLE NETRS	TRM41249.00	DC	20171201

\*(NA = Not Available; MD = Manual Download; DD = Daily Download; DC = Decommissioned)

#### Metadata:

Metadata for the stations PANGA is solely responsible for are available in IGS site log format here:  
[http://www.panga.org/data\\_ftp\\_pub/sites/logs/](http://www.panga.org/data_ftp_pub/sites/logs/)

#### Data Management practices:

Our data management practices conform to the *Geodetic Network Standards and Procedures* as follows:

- We have provided maintenance, and where necessary, replacement of GPS/GNSS receivers and antennas within the PANGA network. We also aid in telemetry solutions for many of our partner sites.
- We have developed a web interface that allows us to check data quality on a daily basis (see Appendix A).
- Our metadata is maintained in IGS site log format and available to the public on our website:  
[http://www.panga.org/data\\_ftp\\_pub/sites/logs/](http://www.panga.org/data_ftp_pub/sites/logs/)
- We host our own website with site information and metadata (see Appendix A).
- All our data that is independent of UNAVCO is archived at a minimum of 30s and made publicly available

- Our system is fully integrated with the Geodesy Seamless Archive (GSAC) utility.
- We maintain our own Ntrip caster and stream RTCM3 data for all real-time sites.
- We provide processed solutions of manually downloaded sites (see Appendix B).

We continue to work on providing PANGA metadata via the web. We now have IGS metadata pages linked off the home PANGA webpage containing time-dependent receiver and antenna types, monument information, GMT station map files, and kml files for Google Earth showing PANGA stations. We continue to maintain our Google Maps PANGA station page and all other metadata sources we currently offer. Metadata we maintain used in the processing (typically our best synthesis of rinex headers, site logs, and other available information) can be found at: [http://www.panga.org/data\\_ftp\\_pub/sites/logs/](http://www.panga.org/data_ftp_pub/sites/logs/). These are IGS standard log files of the most recent upgrades in antennae and receivers we process. We directly maintain over 110 of these site logs while the others are imported from other network operators such as the ORGN, GSC-NRCan, and CVO. Maintaining these log files to ensure quality time-series requires constant communication with our cooperating partners.

[illegible]

USGS Cooperative Agreement G15AC00062 Final Technical Report

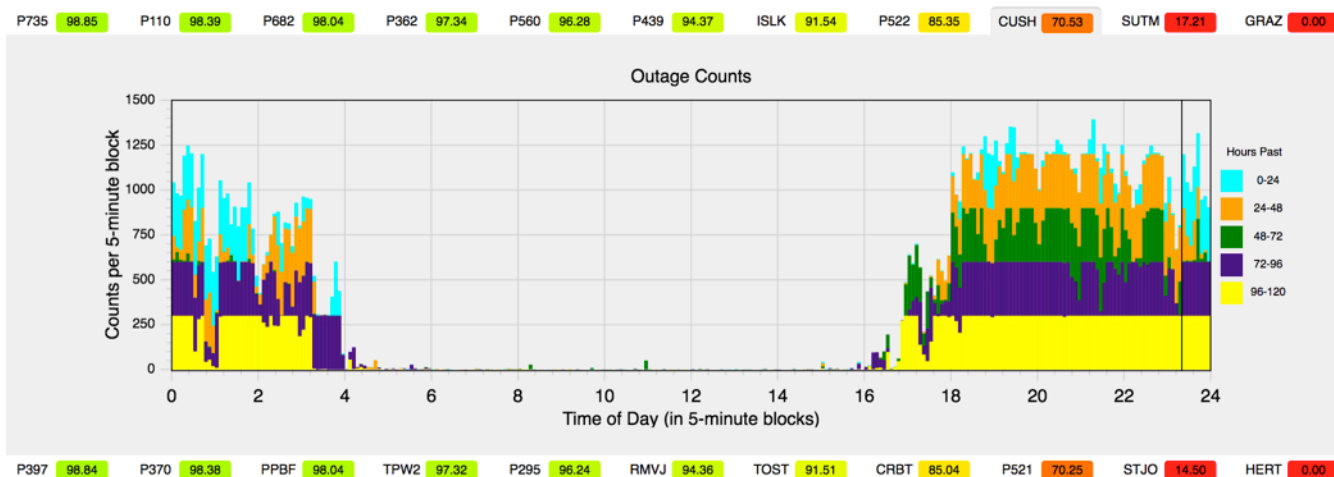


Figure 8: Clicking tab opens site-specific data outages stacked from one to five days. This site CUSH, is consistently reliable from 9pm to 9am local time, and conversely inconsistent during local working/waking hours. This is evidence that there are communication issues, and/or nearby anthropogenic noise.

### Time Series:

For time series, go to [www.panga.cwu.edu](http://www.panga.cwu.edu). In the top (grey) toolbar, click “by Site”. When changing sites, make sure to allow time for the new images to load. Click the separate tabs to toggle between raw, detrended, and cleaned data (see figure 9). Click “Data” to the right of the plots for the source data. We also provide a timeseries tool for direct measurements of transients, offsets, rates and more. Drag the crosshairs to display date and relative position, click and drag to zoom to selection or draw line for instant calculation of offset, rate and time (see figure 10). Another plotting option we offer is “by Region” (see figure 11). These are stacked time series by station latitude (particularly useful when looking for transients). These time series come from two sources: routing NOTA processing and combination where available, otherwise from our internal “PANGA” processing. Green vertical lines denote known ETS events and blue lines are antenna/receiver changes.

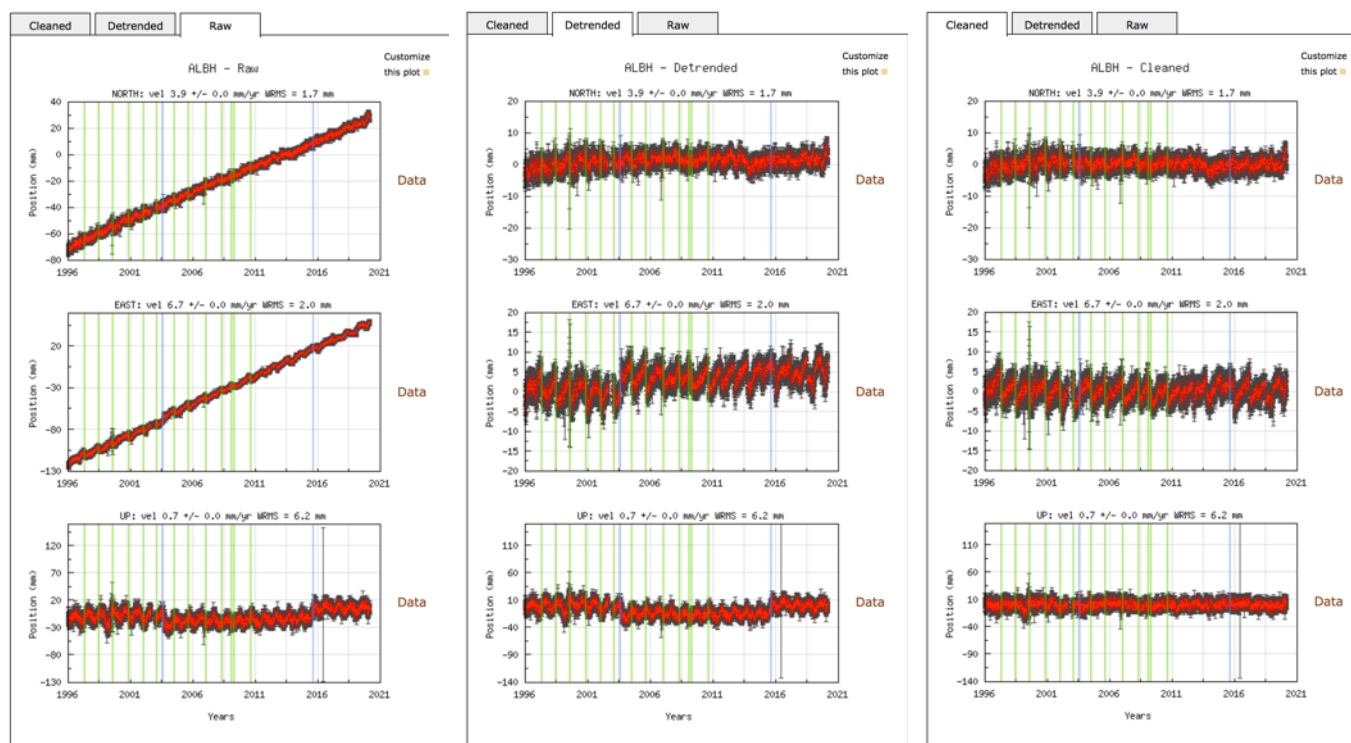


Figure 9: Timeseries “By Site”. Click “Data” to customize time and position scales.

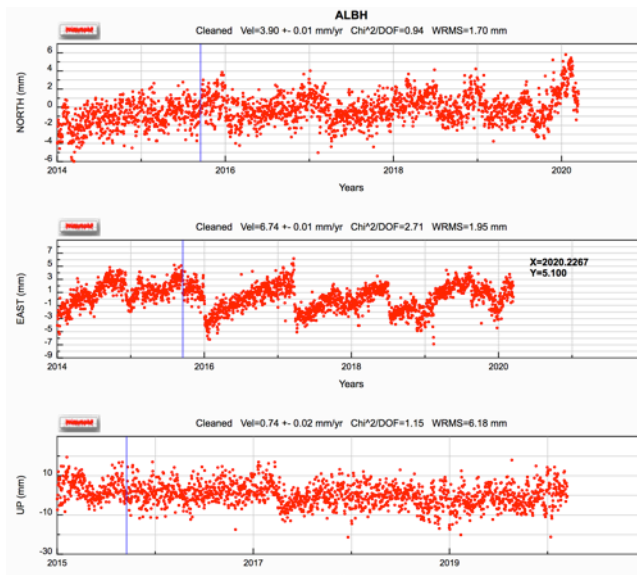
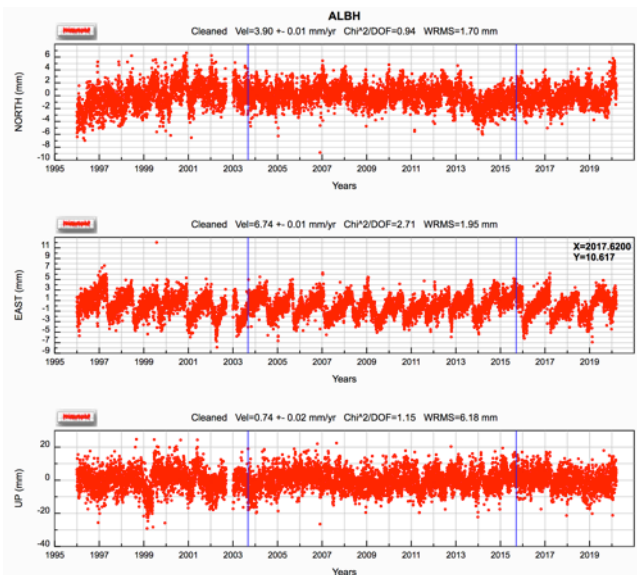


Figure 10: Timeseries tool. Complete timeseries on left and various zoom boxes with cursor time/position readout.

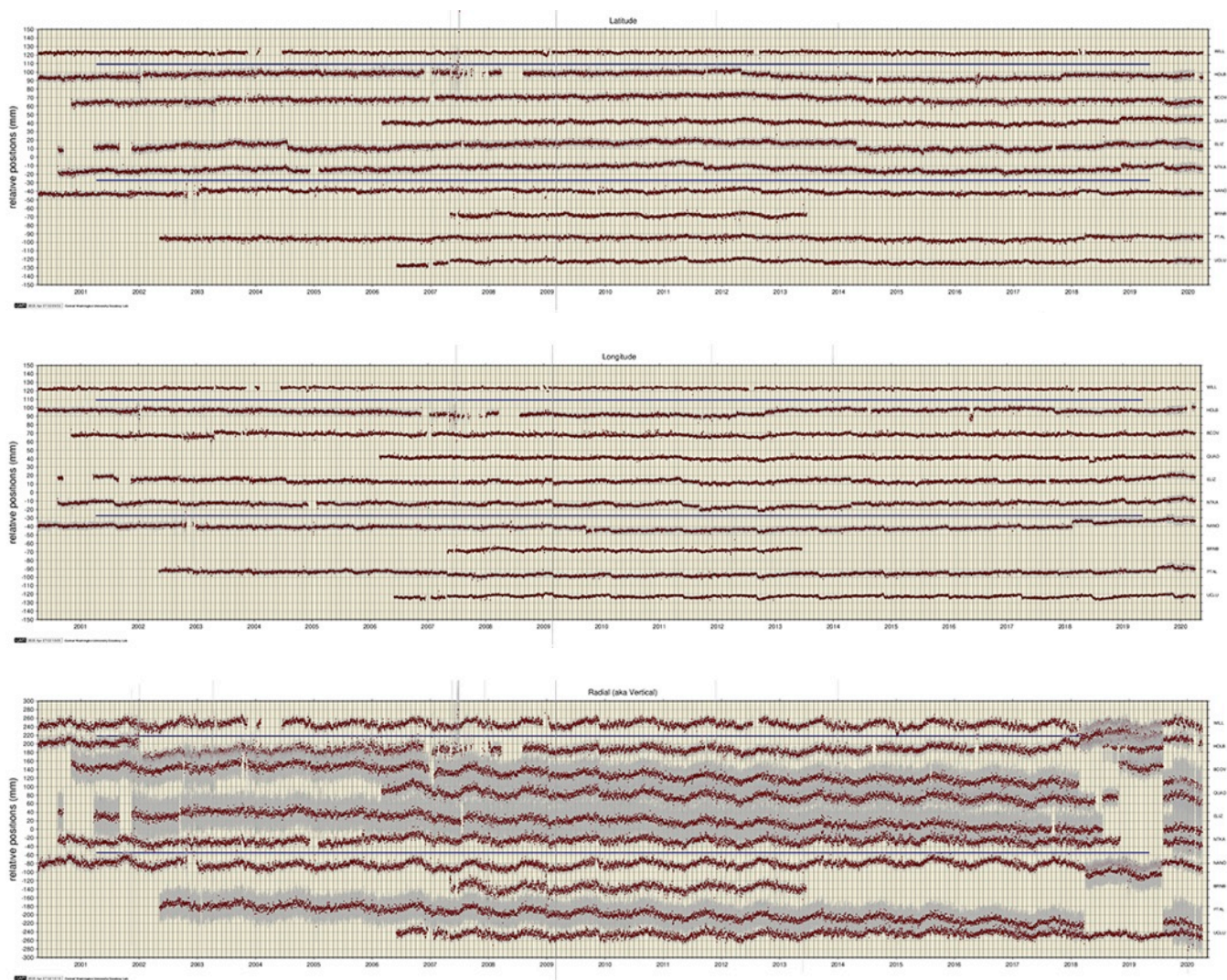


Figure 11: Timeseries "By Region"

## Continuity of Operations and Response Planning

Due to our collaboration with the numerous federal, state, county and private groups involved with RTK surveying, the PANGA network was built and has been maintained with robust real-time monitoring in mind. This has encouraged us to develop processing and earthquake estimation routines to allow quicker and better-informed response to very large ground motions both locally and remotely. “GNSS seismology” is critical for quickly and fully determining the energy release of great earthquakes because it directly measures ground motions, without problems of instrument saturation.

This is not a trivial task: the operational difference between traditional GPS, which relies on static *files* downloaded daily, versus real-time GPS, which uses continuous *streams* of data, is vast. Nearly all software has been written from scratch, since there are no existing tools available to do what we need done. We have made much progress on all fronts, including writing software such as Kalman filters to Q/C incoming streams of phase and range data by flagging and fixing cycle-slips; the processing of those data into station positions in real time using modifications to GIPSY and employing continuous streams of satellite clock and orbit corrections streamed in from processing centers at the IGS and DLR; handling the resultant streams of station positions into a local database (what we call the Aggregator); and servers to disseminate those position streams to clients out on the internet.

We continue to develop our data viewer and navigation program, GPS Cockpit, that capture the real-time position streams from the Aggregator and displays a variety of useful earthquake-related data streams, including peak-ground deformation, vector maps of apparent position, finite-fault estimates of slip along the megathrust, and tsunami excitation. We have increased the number of stations available through our GPS Cockpit software to over 300 sites. The latest version can now be viewed in a simple web browser (see figure 12).

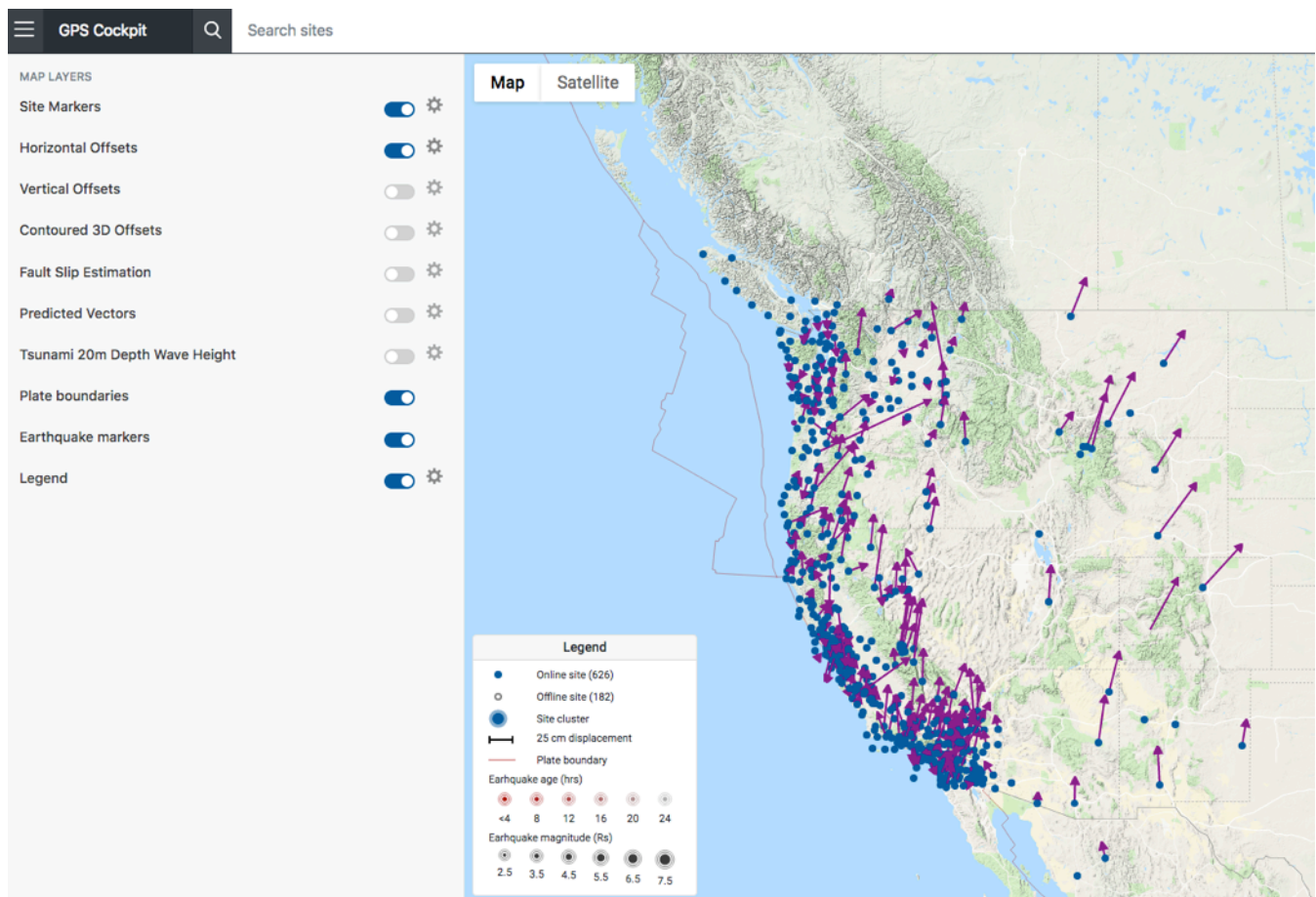


Figure 12: GPS Cockpit GNSS Vectors Web Browser Interface

### **Presentations for further reference:**

[http://www.unavco.org/community/meetings-events/2012/sciworkshop12/plen4\\_melbourne.pptx](http://www.unavco.org/community/meetings-events/2012/sciworkshop12/plen4_melbourne.pptx)  
<http://fallmeeting.agu.org/2012/eposters/eposter/g53b-1148/>

### **Relevant PANGA publications:**

#### Seismic Sensors in Orbit

Timothy I. Melbourne, Diego Melgar, Brendan W. Crowell, and Walter M. Szeliga  
Earth & Space Science News, Volume 101, Number 1, 2020

#### Real-Time High-Rate GNSS Displacements:

Performance Demonstration during the 2019 Ridgecrest, California, Earthquakes

Diego Melgar, Timothy I. Melbourne, Brendan W. Crowell, Jianghui Geng, Walter Szeliga, Craig Scrivner, Marcelo Santillan, and Dara E. Goldberg

Seismological Research Letters Volume XX, Number XX – 2020

doi: 10.1785/0220190223

#### Regional Global Navigation Satellite System Networks for Crustal Deformation Monitoring

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J.P. Montillet, M.S. Bos, T.I. Melbourne, S. D. P. Williams, R. M. Fernandes, W.M. Szeliga  
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#### GPS Vertical Land Motion Corrections to Sea-Level Rise Estimates in the Pacific Northwest

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#### Real-time Monitoring of Tectonic Displacements in the Pacific Northwest through an Array of GPS Receivers

Răzvan Popovici, Răzvan Andonie, Walter M. Szeliga, Timothy I. Melbourne, Craig W. Scrivner

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#### Clustering and Visualization of Geodetic Array Data Streams using Self-Organizing Maps

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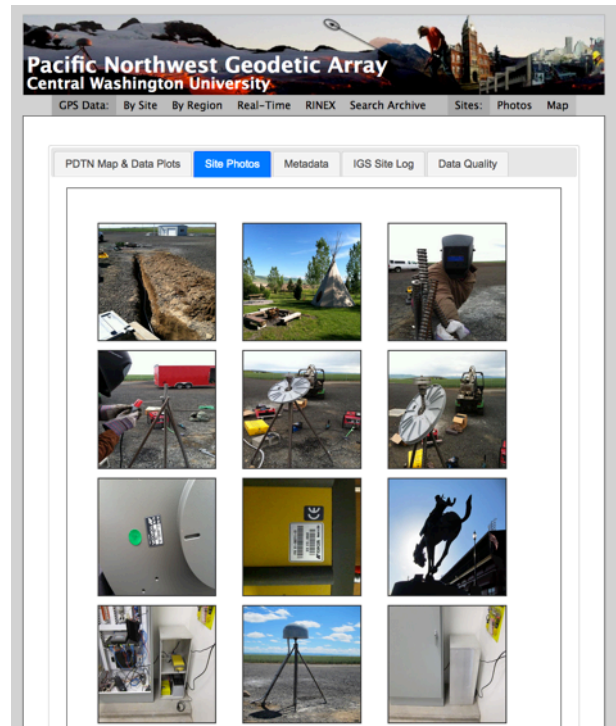
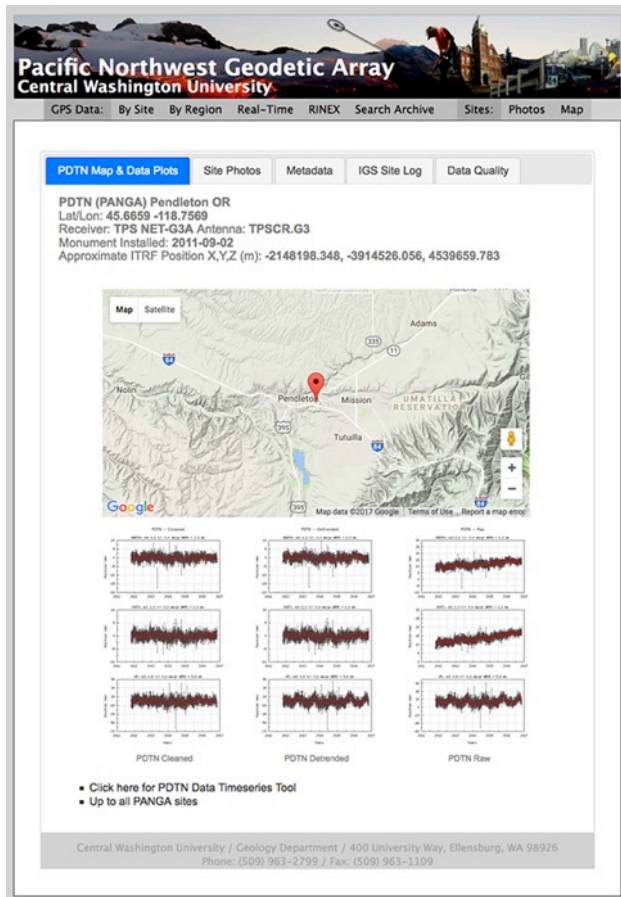
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**\*Full text available here: <http://www.panga.org/about/pubs/>**

**Appendix A: Example of station webpage with tabs for site information/map/timeseries, photos, metadata table and IGS logs, and data quality.**



**Pacific Northwest Geodetic Array**  
Central Washington University

GPS Data: By Site By Region Real-Time RINEX Search Archive Sites: Photos Map

PDN Map & Data Plots Site Photos **Metadata** IGS Site Log Data Quality

Site Information				
Site Name	Code	Subnet	Type	Monument Installed
PENDLETON	PDTN	PANGA	STEEL RODS (Y or URL)	2011-09-02

Site Location Information				
City	State	Latitude	Longitude	Elevation
Pendleton	OR	45.6659	-118.7569	394.5

Approximate ITRF Position X,Y,Z (m)		
X	Y	Z
-2148198.348	-3914526.056	4539659.783

Data Acquisition for CGPS			
Sample Rate	Acquisition Method	Telemetry	Real-Time (Y or N)
1SPS	Telemetered	Ethernet	Yes

Receiver Upgrades and Firmware Updates		
Date Installed	Receiver Type	Firmware Version
9/2/2011	TPS NET-G3A	618-0

Antenna and Domes		
Date Installed	Antenna Type	Dome
9/2/2011	TPSCR.G3	SCIT

Central Washington University / Geology Department / 400 University Way, Ellensburg, WA 98926  
Phone: (509) 963-2799 / Fax: (509) 963-1109

**Pacific Northwest Geodetic Array**  
Central Washington University

GPS Data: By Site By Region Real-Time RINEX Search Archive Sites: Photos Map

PDN Map & Data Plots Site Photos Metadata **IGS Site Log** Data Quality

PDN Site Information Form  
WSRN Continuously Operating Reference Station  
See Instructions at:  
ftp://igschb.jpl.nasa.gov/pub/station/general/sitelog\_instr.txt

0. Form

Prepared by (full name) : cors-adm  
Date Prepared : 2013-08-07  
Report Type : NEW  
If Update:  
Previous Site Log : pdtn\_20111011.log  
Modified/Added Sections : 2

1. Site Identification of the GNSS Monument

Site Name	: PENDLETON
Four Character ID	: PDTN
Monument Inscription	:
IERS DONES Number	:
CDP Number	:
Monument Description	: STEEL RODS
Height of the Monument	: 2 m
Monument Foundation	: STEEL RODS DRILLED AND SET IN BEDROCK
Foundation Depth	: 4.57 m
Marker Description	:
Date Installed	: 2011-09-02
Geologic Characteristic	: BEDROCK
Bedrock Type	:
Bedrock Condition	:
Fracture Spacing	:
Fault zones nearby	:
Distance/activity	:
Additional Information	:

# Pacific Northwest Geodetic Array Central Washington University

GPS Data: By Site By Region Real-Time RINEX Search Archive Sites: Photos Map

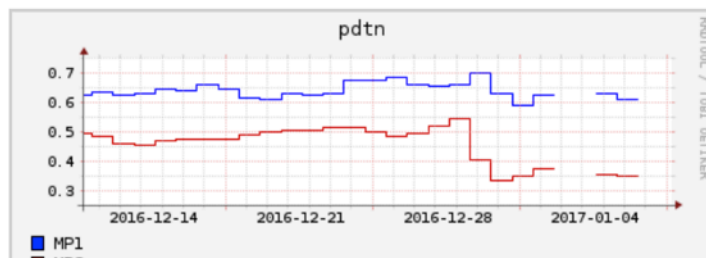
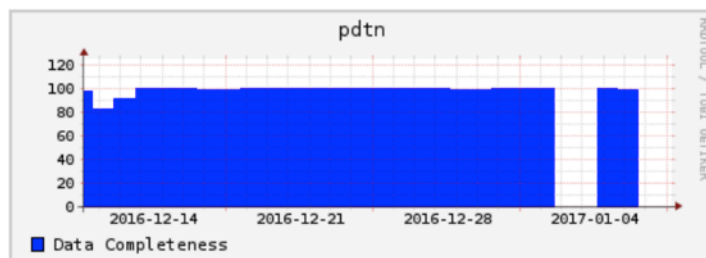
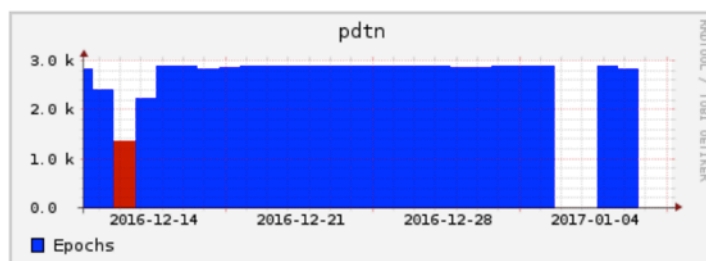
PDTN Map & Data Plots

Site Photos

Metadata

IGS Site Log

Data Quality



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## Appendix B: Campaign sites CRBI, RDTP, QURY and WENA timeseries.

